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551.577.1 : 556.51 (543.1)

Estimation of probable maximum precipitation for Bargi catchment upto Jamtara dam site in Madhya Pradesh

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सार — इस शोधपत्र में नर्मदा नदी पर जमतारा बांध तक बार्गी जलग्रहण के लिए विभिन्न सम्भावनाओं से सम्बन्धित सम्भावित अधिकतम वर्षण के साथ स्टैन्डर्ड प्रोजैक्ट स्टार्म (एस.पी.एस.) का मूल्यांकन करने का प्रयोग किया गया है। सन् 1901 से 1977 ई० तक इस जलग्रहण क्षेत्र में और उसके आसपास होने वाली दैनिक वर्षा के आंकड़ों का परीक्षण लिया गया है। 77 वर्षों के दौरान इस को प्रभावित करने वाले भारी वर्षा तूफानों का विस्तार से अध्ययन किया गया और परियोजना क्षेत्र के लिए विभिन्न मानक समयावधियों के लिए भारी वर्षा की मात्रा का अनुमान लगाया गया है। भारी वर्षा की मात्राओं से परियोजना के लिए स्टैन्डर्ड प्रोजैक्ट स्टार्म (एस.पी.एस.) निकाला गया है और सतह ओस बिन्दु तापमानों की सहायता से नमी अधिकतमीकरण विधि द्वारा पी.एम.पी. मूल्यों को निकाला गया है। पी. एम. पी. मूल्यों की तुलना आवृत्ति विश्लेषण विधि द्वारा निकाले गए वापसी समयावधि के अनुमानों से भी की गई है।

यूनिट हाइड्रोग्राफ विधि द्वारा बाढ़ डिजाइन के अभिकलन में डिजाइन इन्जिनियरों की सुविधा के लिए 24 घन्टे, 48 घन्टे और 72 घन्टे की समयावधि में वर्षा तूफानों का वितरण भी निकाला गया है।

ABSTRACT. An attempt has been made in this paper to evaluate Standard Project Storm (SPS) together with probable maximum precipitation (PMP) for various durations for Bargi catchment upto Jamtara dam site on river *Narmada*. Daily rainfall data in and around the catchment from 1901 to 1977 have been examined. Major rainstorms which affected the region during a period of 77 years were studied in detail and heaviest rain depths for different durations have been estimated for the project area. From the heaviest rain depths the SPS has been derived for the project and PMP values have been obtained by moisture maximisation method considering surface dew point temperature data. PMP values have also been compared with return period estimates obtained by frequency analysis approach.

The time distribution of 24-hr, 48-hr and 72-hr rainstorms have also been carried out to facilitate design engineers in the computation of design flood by unit hydrograph approach.

1. Introduction

Bargi is an irrigation project located in the State of Madhya Pradesh on river *Narmada* near Jamtara in district Jabalpur. The *Narmada* originates in the Amarkantak plateau of Maikal range in Madhya Pradesh at an elevation of 900 m and is flowing in a westward direction. It falls in the Arabian Sea near Gulf of Cambay. The total length of the river is about 1300 km and it drains an area of about 1,00,000 sq. km. The site of the project is located at a distance of about 400 km from the source of the *Narmada*. The catchment of project lies between Lat. 21°45'-23°15'N and Long. 79°45'-81°45'E and extends over an area of about 17000 sq. km respresenting about 17% of the total drainage area of the *Narmada*. An attempt has been made to derive design storm values for various durations for Bargi catchment upto Jamtara dam site so that this information can be useful to the design engineers and hydrologists for determining and reviewing the spillway capacity of the dam.

2. Existing raingauge network and rainfall features of the project catchment

There are 13 raingauge stations located in the project catchment for which long term daily rainfall data are available. Of these, one is an India Met. Dep. observatory station at Mandla equipped with ordinary as well as self recording raingauges and the remaining are State raingauge stations equipped with ordinary raingauges only. Jabalpur is another India Met. Dep. observatory station just outside the catchment which is equipped with ordinary as well as self recording raingauges. The existing network of raingauge stations in and around the catchment is shown in Fig. 1.

The mean annual rainfall of the catchment is of the order of 154 cm and 87% of this rain occurs during four monsoon months of June to September. The highest one-day rainfall recorded at different stations in the catchment is given in Table 1 along with the date and year of occurrence.

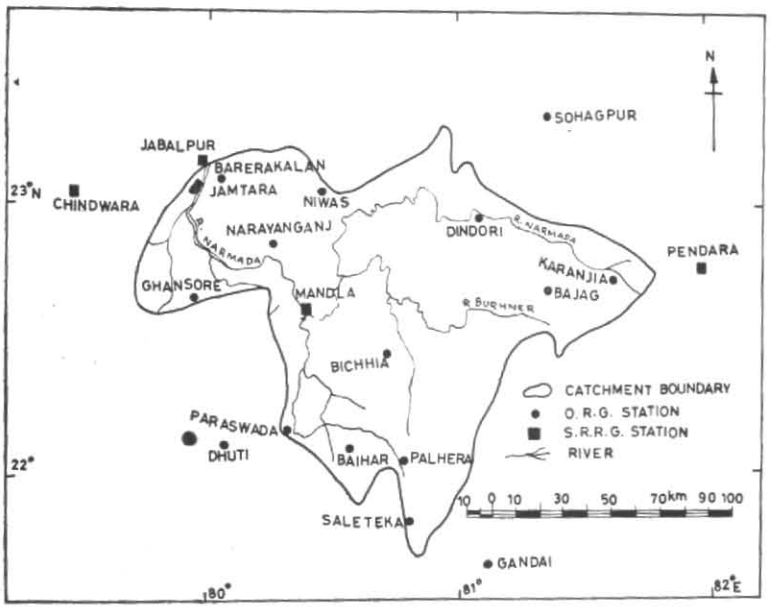

Fig. 1. Index map of Bargi project

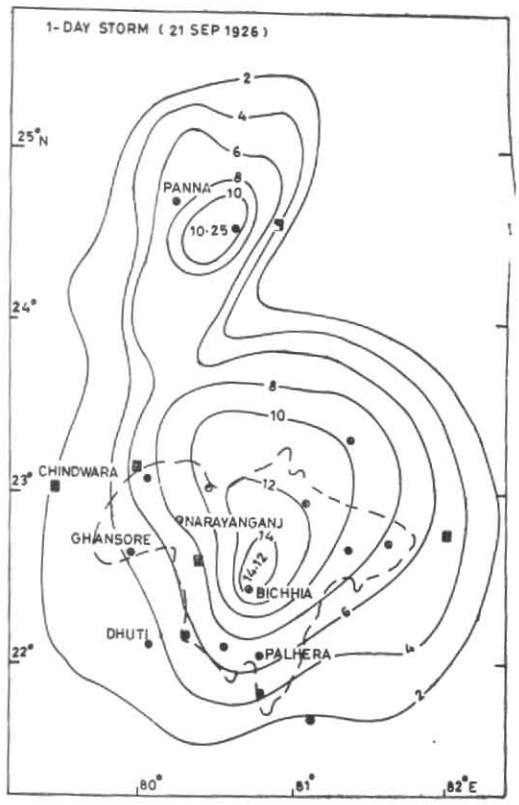

Fig. 2. Isohyetal pattern for (a) 1-day storm (21 September 1926)

TABLE 1

Highest recorded one-day rainfall at raingauge stations in Bargi catchment

District	Station	Date of occurrence	Highest one-day rainfall (cm)	Data available from
Mandla	Narayanganj	20 Sep 1926	23.8	1885
	Dindori	25 Jun 1946	31.7	1885
	Niwas	1 Sep 1970	26.0	1915
	Bajag	21 Sep 1926	24.5	1918
	Bichhia	21 Sep 1926	35.9	1918
	Karanjia	3 Aug 1950	19.2	1944
	Mandla	19 Jul 1869	23.1	1867
Balaghat	Baihar	14 Jul 1875	28.5	1871
	Saleteka	16 Jul 1939	34.9	1927
	Palhera	22 Aug 1931	36.8	1927
	Paraswada	13 Jul 1943	18.0	1927
Seoni	Ghansore	15 Jul 1939	27.1	1922
Jabalpur	Barerakalan	18 Jul 1950	31.0	1927

3. Main synoptic situations responsible for causing heavy rainfall in the project catchment

From an examination of the attendant meteorological situations which were responsible for causing heavy spells of rain and consequent floods over upper Narmada basin of which Bargi catchment forms a part, it has been found that the following meteorological situations were mainly responsible for causing heavy and widespread rainfall over the sub-basin during southwest monsoon season :

(i) Movement of Bay depressions across Orissa and east Madhya Pradesh. Heavy rainfall is caused when the depressions moving westerly/north-westerly directions are centred in the grid indicated by Lat. 21°N-24°N and Long. 84°30'E-87° E.

(*ii*) Monsoon trough lying close to upper Narmada basin, particularly in association with a depression or low over the Bay of Bengal.

(*iii*) Monsoon depressions slowing down or becoming virtually stagnant before recurvature over eastern parts of Madhya Pradesh.

(*iv*) Low pressure areas over northeast Madhya Pradesh are generally associated with increased monsoon activity. There are a few cases of heavy rainfall when low is seen only in the upper air without any corresponding closed low on the sea level chart.

TABLE 2

Average depths of precipitation for different durations of rainstorms over Bargi catchment upto Jamtara dam site

Storm period		Average depths (cm)		
		1-day	2-day	3-day
4–6	Aug 1911	12.5(6)	15.0(5-6)	17.3
29–31	Jul 1915	10.6(30)	18.1(29-30)	22.7
23–25	Sep 1916	11.8(24)	16.8(24-25)	17.9
19–21	Sep 1926	23.0(24)	43.7(20-21)	58.2
26–28	Jul 1928	10.4(27)	14.8(27-28)	16.4
23–25	Aug 1929	10.7(25)	16.0(24-25)	18.4
14–16	Jul 1939	11.6(16)	20.2(15-16)	24.1
23–25	Jun 1946	13.0(25)	17.8(24-25)	19.6
13–15	Aug 1968	11.2(14)	17.8(13-14)	22.2
1–3	Jul 1970	10.2(2)	13.6(1-2)	16.6

Note : Figures in brackets indicate date/dates of the rainstorm

4. Selection of rainstorms and their analysis for design storm studies

The rainstorms were selected by an inspection of daily rainfall data of all the raingauges in and around the project catchment. Rainfall data of stations after 1977 were not readily available and as such the study was confined to the period 1901 to 1977. In order to limit the study to relatively heavy storm, the following criteria was adopted for selection of rainstorms of different durations :

1-day rainstorm — Arithmetic average rainfall of 8 cm and above over the catchment.

2-day rainstorm — Arithmetic average of at least 8 cm on one of the days and 4 cm on the preceding or succeeding day of the storm over the catchment.

3-day rainstorm — Arithmetic average rainfall of at least 8 cm on one of the days, 4 cm on preceding or succeeding day and 2 cm on the third day in a continuous spell of 3 days over the catchment.

Using above criteria, the major storms of 3-day duration experienced in and around the Bargi catchment were selected with catchment area as unity. All these rainstorms with their average rainfall depths (by Arithmetic mean method) in the catchment are given in Table 2.

5. Depth-duration analysis

It is seen from Table 2 that the rainstorm of 19-21 September 1926 contributed the highest average depths of precipitation over the catchment for 1-day, 2-day and 3-day durations and this rainstorm which is the heaviest in this region may be adopted to obtain standard *project storm values. 1-day, 2-day and* 3-day isohyetal maps were, therefore, prepared for carrying out detailed analysis of the storm in question. Taking the catchment as the unit of study, the following maximum depths of rainfall, which are in fact the Depth-Duration (D.D.) values for the catchment, were obtained :

Duration	*Depth-duration (D. D.)values*
1-day	23.1 cm
2-day	45.0 cm
3-day	61.5 cm

A critical examination of the isohyetal pattern of this rainstorm showed that it was centred in the problem basin and gave very concentrated rainfall in and around the catchment of Bargi project. Therefore, in order to obtain standard project storm (SPS) values for Bargi project, the storm was taken as unit and average rainfall depths for the area corresponding to Bargi project obtained. The standard project storm values for Bargi project are :

Duration	*Standard Project Storm values*
1-day	26.5 cm
2-day	46.0 cm
3-day	65.5 cm

The isohyetal pattern for rainstorm of 19-21 September 1926 for 1-day, 2-day and 3-day durations are given in Figs. 2 to 4 and Depth-Area-Duration (D.A.D.) curves in Fig. 5.

6. Synoptic situation responsible for the rainstorm of 19-21 September 1926

A depression formed approximately near Lat. 16°N, Long. 89°E on the morning of 14th. Moving initially in a northwesterly direction the depression intensified into a cyclonic storm and was centred near Lat. 18°N, Long. 87° E on the morning of 15th. Thereafter, it moved for next two days in northnorthwesterly direction and lay over north Orissa on the morning of 17th, the centre having crossed the coast near False Point during the night of 16-17 September. From north Orissa the storm weakened into a depression while moving through the east of Madhya Pradesh on the 18th and reached near Satna on 19th where it remained almost stationary upto 23rd and became unimportant thereafter.

The heavy rain which occurred during this period resulted in serious floods in Bargi catchment and caused extensive damages in Jabalpur, Mandla and neighbouring districts of Madhya Pradesh. Mandla was the worst affected. Damage to life, cattle, houses and crops was extensive in flooded area. The civil station, Mandla was entirely submerged.

7. Estimation of Probable Maximum Precipitation (PMP) — Physical approach

According to the Glossary of American Meteorological Society (1959), Probable Maximum Pecipitation has been defined as that greatest depth of precipitation for a given duration which is physically possible over a drainage basin. The main aim of PMP is, therefore, to obtain such an estimate of rainfall which will guide a design engineer in designing the spillway capacity of a

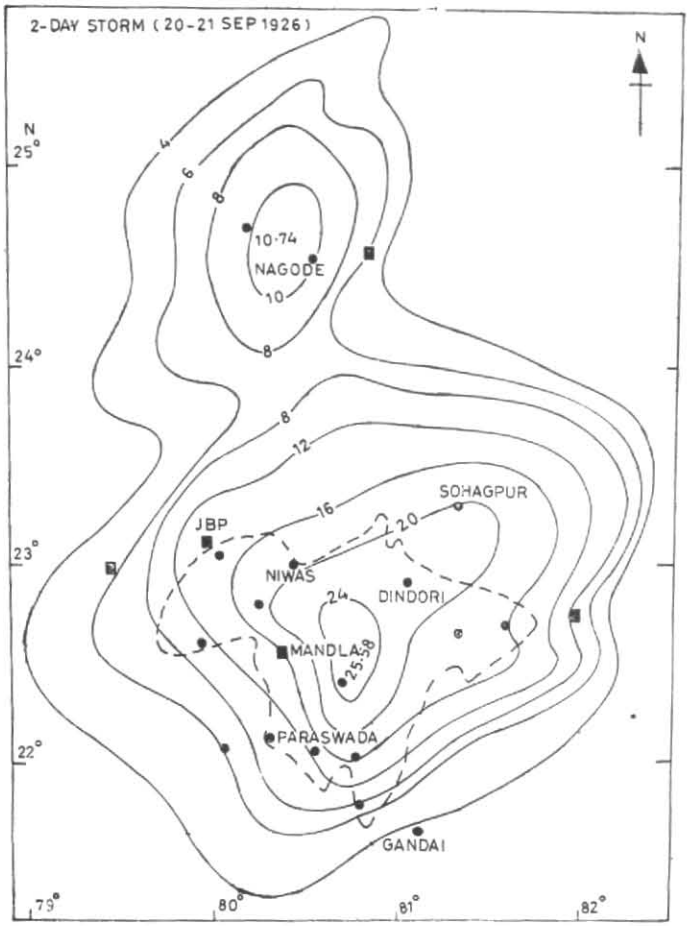

Fig. 3. Isohyetal pattern for 2-day storm (20-21 Sep 1926)

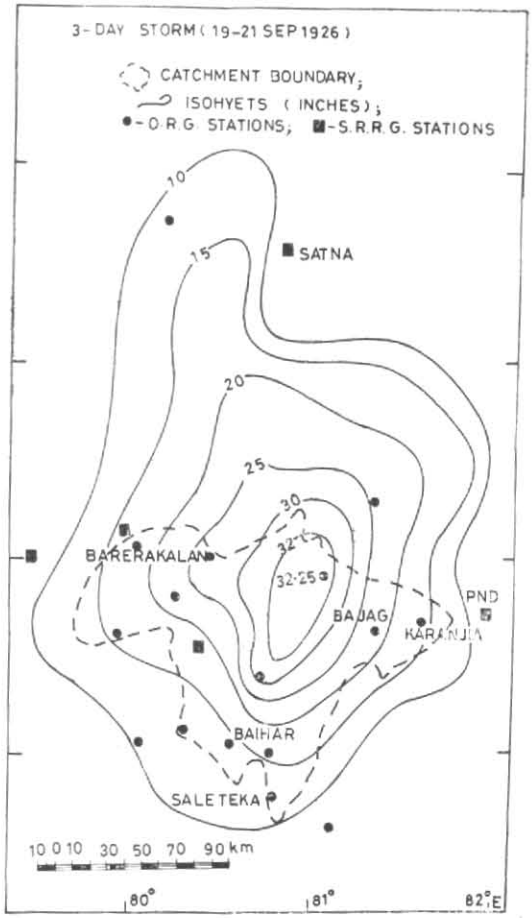

Fig. 4. Isohyetal pattern for 3-day storm (19-21 Sep 1926)

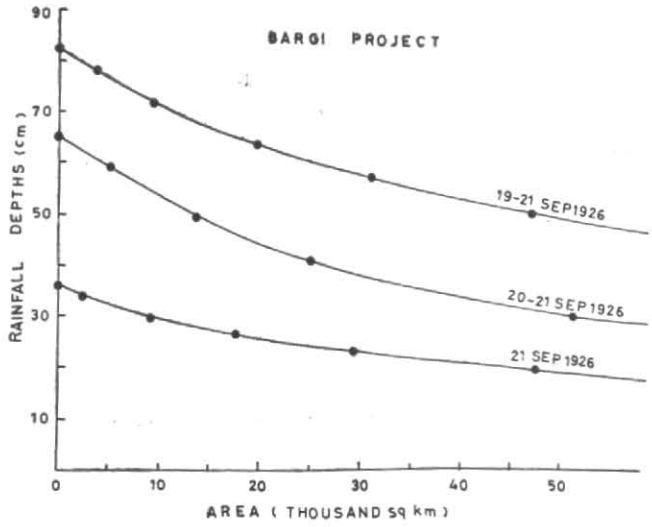

Fig. 5. Depth area-duration curves for Bargi project

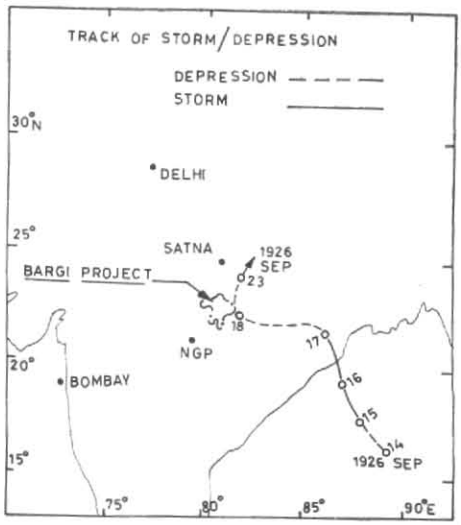

Fig. 6. Track of storm-depression, 14-23 Sep 1926

TABLE 3

Maximum raindepths (cm) over Bargi catchment upto Jamtara dam site for different durations and return periods

Duration	100-yr	500-yr	1000-yr	5000-yr	10,000-yr
1-day	16.7	20.3	21.8	25.4	26.9
2-day	26.3	31.9	34.3	40.0	42.4
3-day	32.5	39.4	42.4	49.3	52.3

TABLE 4

Time distribution values (%) of 24, 48 and 72-hr storm rainfall recommended for Bargi catchment in Madhya Pradesh

Duration (hr)	Percentage of storm rainfall		
	24-hr	48-hr	72-hr
3	50	..	..
6	63	34	..
9	72	..	17
12	79	47	..
15	85	..	..
18	91	57	31
21	96	..	..
24	100	66	..
27	..	..	43
30	..	75	..
36	..	84	55
42	..	92	..
45	..	..	67
48	..	100	..
54	..	..	78
63	..	..	89
72	..	..	100

dam which under all circumstances preludes the possibility of endangering the structure of the proposed dam.

The method currently in use to obtain Probable Maximum Precipitation (PMP) for a basin or catchment is "Moisture Maximisation" procedure. It is based on two assumptions (*i*) that the rainfall has occurred as a result of moisture influx and the combined effect of storm efficiency and inflow wind and (*ii*) that the most effective combination of storm efficiency and inflow wind has either occurred or has closely approached the major storm on record (Bruce 1959). Under the later assumption, all that is required is to adjust the heaviest storm on record over that region for optimum moisture charge obtained on consideration of surface dew point temperatures of representative stations in and around the catchment. The factor by which the *storm is maximised* for moisture charge is called "Moisture Adjustment Factor (MAF)" for the rainstorm and is defined as the ratio of the maximum precipitable water that could be available during that part of the season in a unit cross-sectional vertical column of the atmosphere during the storm period under consideration.

The storm of 19-21 September 1926 has been maximised for moisture charge to obtain PMP values. The MAF has been worked out for the storm in question on the basis of persisting storm and the corresponding maximum dew point data of the representative station for the catchment. The standard procedure adopted in India Met. Dep. as per WMO Report No. 332 (1973) was followed, using U.S. Weather Bureau diagram as modified by Pramanik and Hariharan (1951), for computation of precipitable water depths corresponding to (*i*) the maximum dew point temperature and (*ii*) persistent storm dew point. MAF works out to be 1.36 for the storm of 19-21 September 1926 for this project. The following values obtained by applying MAF of 1.36 to the SPS values may be adopted as PMP values of various durations for the project :

Duration	*PMP values (cm)*
1-day	36.0
2-day	62.6
3-day	89.1

One-day SPS and PMP values may further be increased by 15% to convert them to any 24-hr value for design purposes.

8. Frequency approach

The maximum raindepth data of the catchment for different durations and return periods are quite useful to project engineers while designing spillway capacity of dams as it provides cross-checking of design storm values by physical method with return period estimates computed by frequency analysis approach. The annual maximum raindepth series for Bargi catchment upto Jamtara dam site for 1-day, 2-day and 3-day durations for 77-year period were treated by Gumbel's extreme value technique using the method of least squares. Maximum raindepths for the catchment for durations of 1, 2 and 3-day and return periods of 100, 500, 1000, 5000 and 10000 years were worked out and the data are given in Table 3.

It is seen from Table 3 that the PMP values obtained by physical method for 1-day, 2-day and 3-day durations far exceed the raindepth values corresponding to 10,000 yr return period. The SPS values for different durations derived by physical approach appear somewhat comparable to 10,000-yr return period estimates by frequency approach. There seems to be no definite pattern in relationship between PMP by physical approach and a fixed return period by statistical method.

The PMP values obtained by moisture maximisation method are recommended for Bargi project.

9. Time distribution of storm rainfall

The design engineers generally require 3-hourly or 6-hourly time distribution of storm rainfall for determining storm hydrograph characteristics. An attempt has been made to compute time distribution of storm rainfall for Bargi project on the basis of available clock hour rainfall data of Mandla and Jabalpur self recording raingauge stations.

The procedure adopted for selection of rainstorms for time distribution analysis was that (*i*) break in rainfall should not ordinarily exceed three consecutive hours and there are at least 15 to 18 rainy hours in 24-hour storms; (*ii*) break in rainfall should not exceed six consecutive hours and there are at least 33 to 36 rainy hours in 48-hour storms and (*iii*) break in rainfall should not exceed nine consecutive hours and there are atleast 51 to 54 rainy hours in 72-hour storms.

For selection of these storms clock hour rainfall data of 2 to 5 observational days were scanned and any 24-hr, 48-hr and 72-hr spells during which maximum rainfall occurred were selected.

Time distribution analysis was carried out on the basis of 3 consecutive clock-hour rainfall data for each rainstorms of 24, 48 and 72-hr periods. In each rainstorm any 3-hr duration in which maximum rainfall recorded was selected. This maximum rainfall value of each storm was expressed as percentage of 24-hr, 48-hr and 72-hr rainfall value as the case may be. The same procedure was followed for obtaining 6-hr, 9-hr etc durations maximum rainfall in respect of 24, 48 and 72-hr rainstorms.

The percentages thus computed for each duration for each storm were plotted against duration and time distribution curves drawn. The time distributions of 24-hr, 48-hr and 72-hr storm rainfall computed on the basis of hourly rainfall data of Mandla and Jabalpur self recording raingauge stations are given in Table 4. This time distribution is recommended for Bargi project for 24, 48 and 72-hr storm rainfall.

10. Conclusions

From this study the following broad conclusions may be drawn :

(*a*) The average annual rainfall of Bargi catchment upto Jamtara dam site is of the order of 154 cm.

(*b*) From the examination of all heavy rainspells that occurred over the project area during 77-year period from 1901 to 1977, it is revealed that the rainstorm of 19-21 September 1926 has contributed the highest average depths of 26.5 cm, 46.0 cm and 65.5 cm for 1, 2 & 3-day durations over the project area.

(*c*) During the 3-day rainspell, the project area experienced about 43% of the mean annual rainfall. 70% of this occurred in just 2 days.

(*d*) PMP values have been worked out by the conventional moisture maximisation method. The moisture adjustment factor has been found to be 1.36.

(*e*) Average annual maximum raindepths for 1, 2 and 3-day durations experienced by the project area during 77-yr period were subjected to frequency analysis. It is observed that PMP values estimated by moisture maximisation method far exceed the raindepth values corresponding to 10,000-yr return period. Standard Project Storm (SPS) for the catchment has been found to have return period of the order of 10,000 years.

(*f*) The study has revealed that there is no definite relationship between PMP values obtained by physical approach and those obtained by assigning a fixed return period by statistical approach. The SPS and the PMP values obtained by physical approach are recommended for Bargi project.

(*g*) Time distribution values of 24, 48 and 72-hr storm rainfall to be adopted for the project have been worked out and are given in Table 4.

Acknowledgement

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